H2@Scale Program Multi-Party Cooperative Research and Development Agreement: California Hydrogen Infrastructure Research Consortium Task

Cooperative Research and Development Final Report

CRADA Number: CRD-18-00754

NREL Technical Contact: Sam Sprik

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-82672
May 2022

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Suggested Citation

Sprik, Sam. 2022. *H2@Scale Program Multi-Party Cooperative Research and Development Agreement: California Hydrogen Infrastructure Research Consortium Task: Cooperative Research and Development Final Report, CRADA Number CRD-18-00754.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-82672. https://www.nrel.gov/docs/fy22osti/82672.pdf.

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Cooperative Research and Development Final Report

Report Date: April 14, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement:

- Alliance for Sustainable Energy -National Renewable Energy Laboratory (NREL)
- California Governor's Office of Business and Economic Development (GO-Biz)
- South Coast Air Quality Management District (SCAQMD)
- California Energy Commission (CEC)

CRADA Number: CRD-18-00754

CRADA Title: H2@Scale Program Multi-Party Cooperative Research and Development Agreement: California Hydrogen Infrastructure Research Consortium Task

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Hydrogen and Fuel Cell Technologies Office (HFTO)

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources
Year 1	$ 270,000
Year 2	$ 270,000
Totals	$ 540,000

Executive Summary of CRADA Work:

Many stakeholders are working on hydrogen and fuel cell products, markets, requirements, mandates, and policies. California has been leading the way for hydrogen infrastructure and fuel cell electric vehicle (FCEV) deployment. This leadership has advanced a hydrogen network that is not duplicated anywhere in the United States and is unique in the world for its focus on providing a retail fueling experience. In addition, the advancements have identified many lessons learned for hydrogen infrastructure development, deployment, and operation. Other interested states and countries are using California's experience as a model case, making success in California paramount to enabling market acceleration and uptake in the United States. The technical research capability of the national laboratories can be used to assist California in decisions and evaluations, as well as to verify solutions to problems impacting the industry. Because these challenges cannot be addressed by one agency or one laboratory, a hydrogen research consortium has been organized to combine and collaborate. The collaboration aims to:

- Ensure that data are available to evaluate projects and inform decision makers
- Independently verify and validate component solutions
- Provide experimental results for future hydrogen infrastructure
- Increase the availability of technical experts for quick-need issues for California hydrogen infrastructure development, deployment, operation, and technology advances.

The proposed tasks include data collection from operational stations, component failure fix verification (i.e. nozzle freeze lock), new fueling methods for medium and heavy duty applications, and ensuring hydrogen quality is maintained. U.S. leadership for hydrogen technologies is rooted in California, a location for implementing many H2@Scale pathways such as reducing curtailment and stranded resources, reducing petroleum use and emissions, and developing and creating jobs.

Summary of Research Results:

Overall Summary Introduction

The work described in this report was performed as part of a consortium between NREL and California agency partners. The tasks included hydrogen station data analysis, insights into medium and heavy-duty vehicles running on hydrogen, hydrogen contaminant detectors for use at hydrogen refueling stations, hydrogen nozzle freeze lock evaluation, hydrogen topics for integration into the California energy management strategy, and a technical assistance project that analyzed liquid hydrogen modeling for a hydrogen station capacity tool. An additional and final task was to develop this final report. The tasks outcomes are summarized below under each task heading. A modification to the CRADA simply extended the term to complete the previously defined task work.

Task 1 Title: Data Collection & Analysis

Task 1 Description

The goal of this task is to perform analysis and aggregation of station performance, operation, and maintenance data. The Energy Commission will continue to provide station operation data according to NREL's Fuel Cell and Hydrogen Technology Validation program, MOU-15-404.

Task 1 Summary and Outcomes/Results:

Through regularly supplied station data, this task has published on a bi-annual basis composite data products (CDPs) that aggregate and anonymize data from individual stations in order to provide a snapshot of the state of the technology. Analysis topics include deployment, performance, utilization, energy, cost, reliability, safety, and hydrogen quality. The work is performed as part of NREL's National Fuel Cell Technology Evaluation Center, which performs third-party evaluation of a variety of real-world applications around hydrogen and fuel cells.

The result of the task has been to publish four publication collections of CDPs since May 2018 as well as individual charts. Additionally, results have been presented as part of DOE's Annual Merit Review 2018-2021, DOE H2@Scale Working Group, and at the 2019 Fuel Cell Seminar and Energy Exposition. A listing of the publications is provided below.

Composite Data Products
(current versions available at https://www.nrel.gov/hydrogen/hydrogen-infrastructure-analysis.html)

- Sam Sprik, Jennifer Kurtz, Genevieve Saur, Shaun Onorato, Matthew Ruple, Chris Ainscough. 2018. *Next Generation Hydrogen Station Composite Data Products: Retail Stations, Data through Quarter 4 of 2017*. NREL/PR-5400-71645. https://www.nrel.gov/docs/fy18osti/71645.pdf.
- Sam Sprik, Jennifer Kurtz, Genevieve Saur, Spencer Gilleon. 2019. *Next Generation Hydrogen Station Composite Data Products: Retail Stations, Data through Quarter 4 of 2018*. NREL/PR-5400-73658. https://www.nrel.gov/docs/fy19osti/73658.pdf.
- Genevieve Saur; Spencer Gilleon; Sam Sprik. 2020. *Next Generation Hydrogen Station Composite Data Products: Retail Stations, Data through Quarter 3 of 2019*. NREL/PR-5400-76588. https://www.nrel.gov/docs/fy20osti/76588.pdf.
- Genevieve Saur; Spencer Gilleon; Sam Sprik. 2021. *Next Generation Hydrogen Station Composite Data Products: Retail Stations, Data through Quarter 2 of 2020.* https://www.nrel.gov/hydrogen/assets/pdfs/next-gen-hydrogen-retail-stations-q2-2020.pdf

Presentations:

- Genevieve Saur; Sam Sprik; Jen Kurtz; Shaun Onorato; Spencer Gilleon; Erin Winkler; Mike Peters. 2019. Technology Validation of Hydrogen Refueling Infrastructure. NREL/PR-5400-77950. https://www.nrel.gov/docs/fy21osti/77950.pdf.
- Genevieve Saur; Spencer Gilleon; Sam Sprik. 2020. Fueling Station Component Validation. NREL/PR-5400-76846. https://www.nrel.gov/docs/fy20osti/76846.pdf.
- Sam Sprik; Jen Kurtz; Chris Ainscough; Genevieve Saur; Shaun Onorato; Matt Ruple. 2018. Hydrogen Station Data Collection and Analysis. DOE Hydrogen and Fuel Cells Program 2018 Annual Merit Review and Peer Evaluation Meeting. https://www.hydrogen.energy.gov/pdfs/review18/tv017_sprik_2018_o.pdf
- Genevieve Saur; Sam Sprik; Jen Kurtz; Shaun Onorato; Spencer Gilleon; Erin Winkler. 2019. Hydrogen Station Data Collection and Analysis. DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting. https://www.hydrogen.energy.gov/pdfs/review19/ta014_sprik_2019_o.pdf
- Genevieve Saur; Spencer Gilleon; Sam Sprik. 2020. Fueling Station Component Validation. DOE Hydrogen and Fuel Cells Program 2020 Annual Merit Review and Peer Evaluation Meeting. https://www.hydrogen.energy.gov/pdfs/review20/in023_saur_2020_o.pdf

The task has tracked deployed hydrogen refueling stations in California and continued a project that tracked retail stations and previously non-retail stations in the region. Figure 1 shows the deployment of retail stations starting in 2015 along with when different FCEV models were introduced and total sales numbers. Data in other CDPs represent a subset of stations providing data either through solicitation agreements or voluntarily.

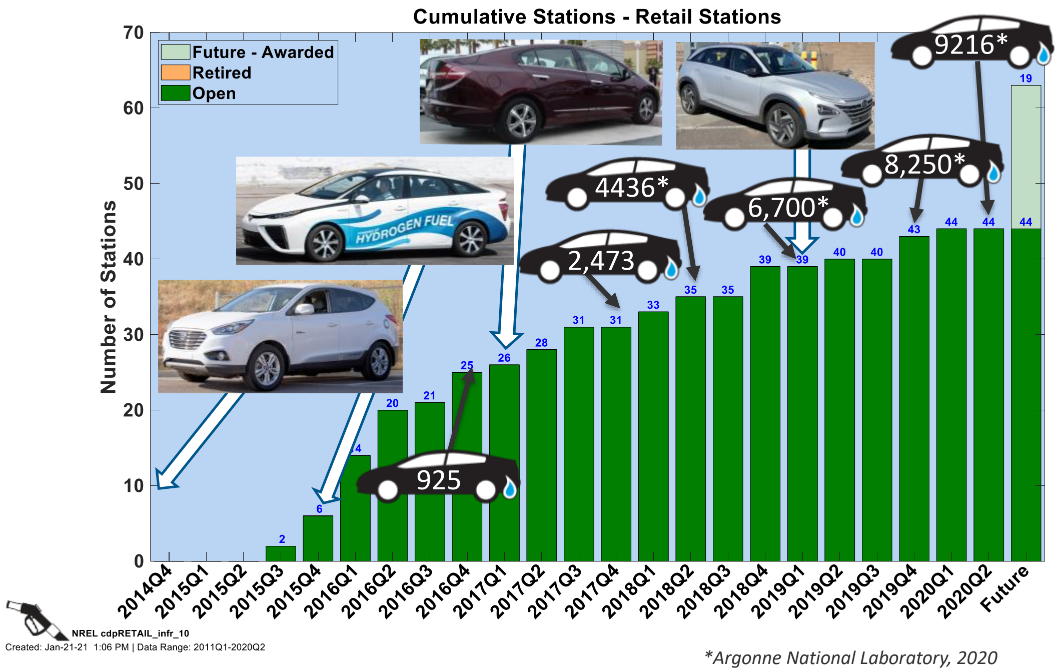


Figure 1. Adapted from CDPRetail-INFR-10 to show deployment of stations in California along with introduced FCEVs and total sales numbers.

The number of stations that report data has varied over time based on reporting requirements. Figure 2 shows the number of stations reporting and the cumulative hydrogen dispensed at those stations by station and quarter. In quarter 2 of 2020, there were 44 stations in operation while 35 were reporting data as part of this project. The average amount of hydrogen dispensed per station in quarter 2 of 2020 was 3,549 kilograms (kg) of hydrogen. Results like this help to chart the growth of the industry over time.

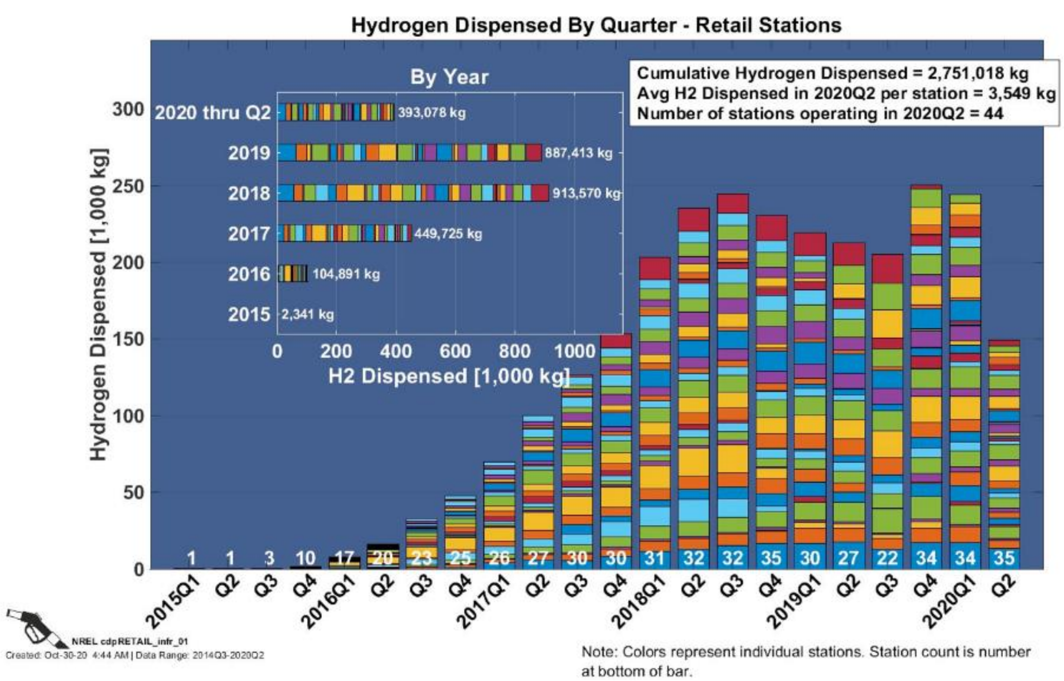


Figure 2. CDPRetail-INFR-01 shows cumulative H2 dispensed by quarter and station.

Over the course of the project we have seen stations nearing daily averages of 100 kg/day (CDPRetail-INFR-82, Figure 3), and maintenance costs per kg of hydrogen dispensed have been trending down (CDPRetail-INFR-53, Figure 4). Both are good trends showing improvements and utilization of the technology with some noticeable impacts due to Covid-19 in the later quarters.

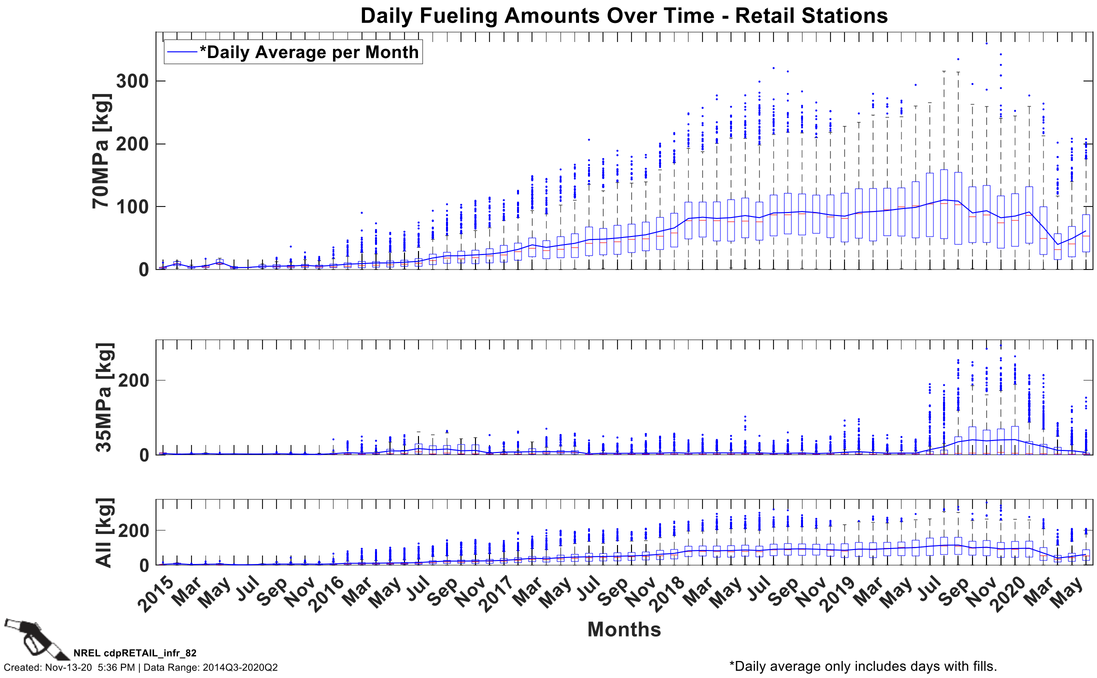


Figure 3. CDPRetail-INFR-82

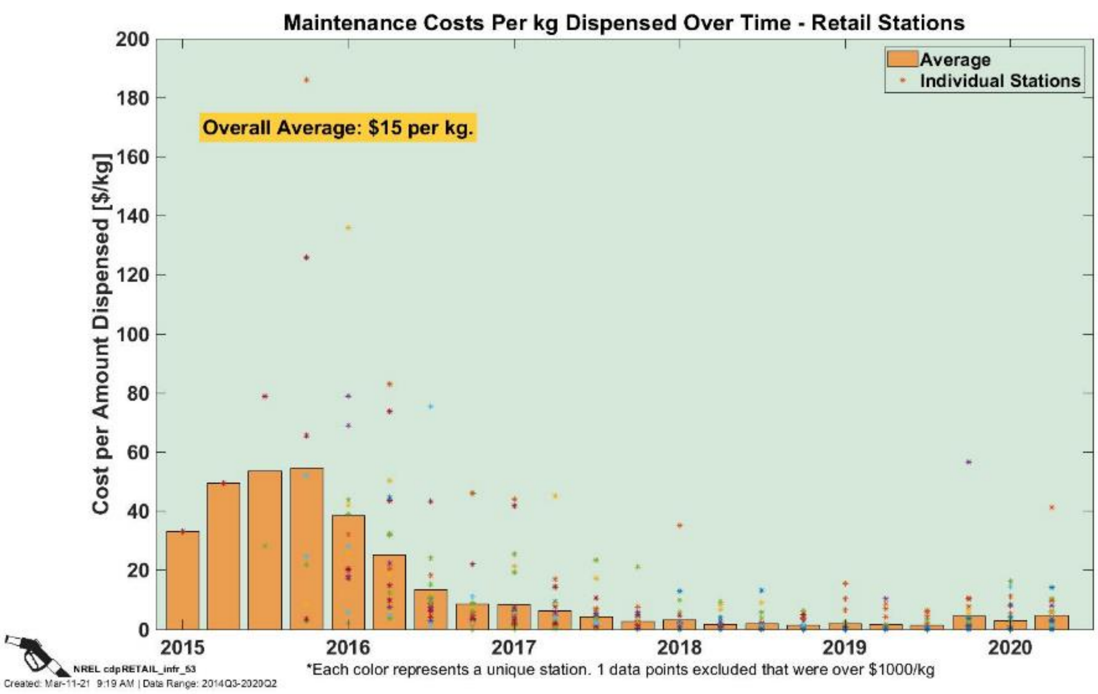


Figure 4. CDPRetail-INFR-53

This project has helped identify the research and development (R&D) needs of the industry related to station maintenance and reliability through 24 CDPs on these topics. CDPRetail-INFRA-21, shown in Figure 5, was developed to highlight the components most at issue by frequency of event and amount of repair time. Other analyses of these data include trends over time and reliability calculations.

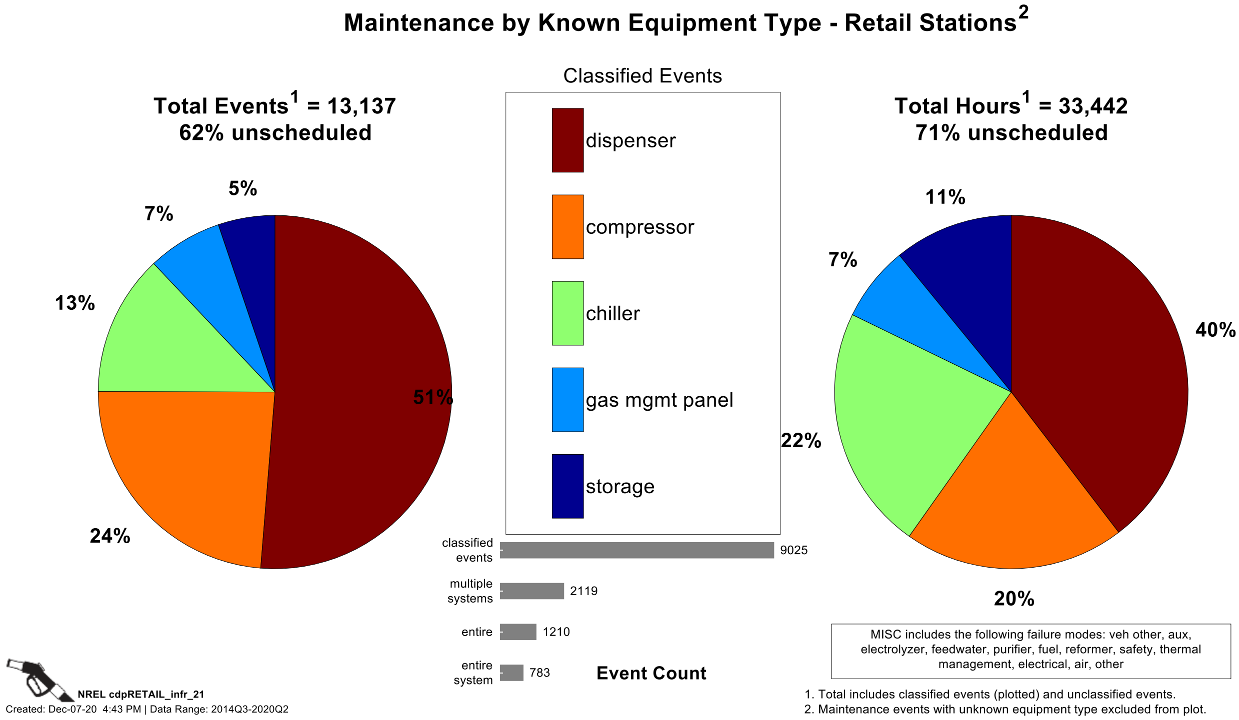


Figure 5. CDPRetail-INFRA-21 Aggregated maintenance data from retail stations 2014-2020

During the project, we developed and published five new analyses, bringing the total number published to 102 CDPs, which evaluate hydrogen refueling stations on a variety of topics: deployment, performance, utilization, energy usage, cost, reliability, safety, and hydrogen quality. These topics provide utility to a range of stakeholders, from government officials evaluating incentivized deployment programs and R&D needs to station owners and operators evaluating the current market to developers assessing component requirements.

Full results are published in the above referenced reports.

Task 2 Title: Medium-/Heavy-Duty Fueling

Task 2 Description

The goal of this task is to perform analysis and reporting of retail and experimental fueling data to inform fueling system design.

Task 2 Summary and Outcomes/Results:

This task was originally intended to analyze and report on retail and experimental fueling of medium-/heavy-duty trucks. The task was redirected towards a topical overview of medium/heavy duty truck fueling that resulted in a report and a presentation suitable for a webinar that was shared with the California partners for their use as needed. A webinar was organized by the California partners and attended by 78 people from various government organizations in California. Webinar topics brought together existing capabilities and planned work and included “Life Cycle Implications of HD Vehicles”, “Medium- and Heavy-Duty Transportation R&D”, “Overview of Scenario Evaluation and Regionalization Analysis (SERA) Model”, “Applications SERA for FCEV Adoption”, “Market Segmentation”, “Hydrogen Financial Analysis Scenario Tool (H2FAST)”, “Hydrogen Stations and DC Fast Charging”, and “Hydrogen Station and Vehicle Field Data”. The graphic from the webinar depicted in Figure 6 shows how the markets for trucks and cars complement each other, with the larger number of light duty vehicles providing the possibility for larger-scale production of parts that can bring down the prices for components used in trucking, and with trucks using much more hydrogen fuel that can bring down the price of hydrogen for light duty.

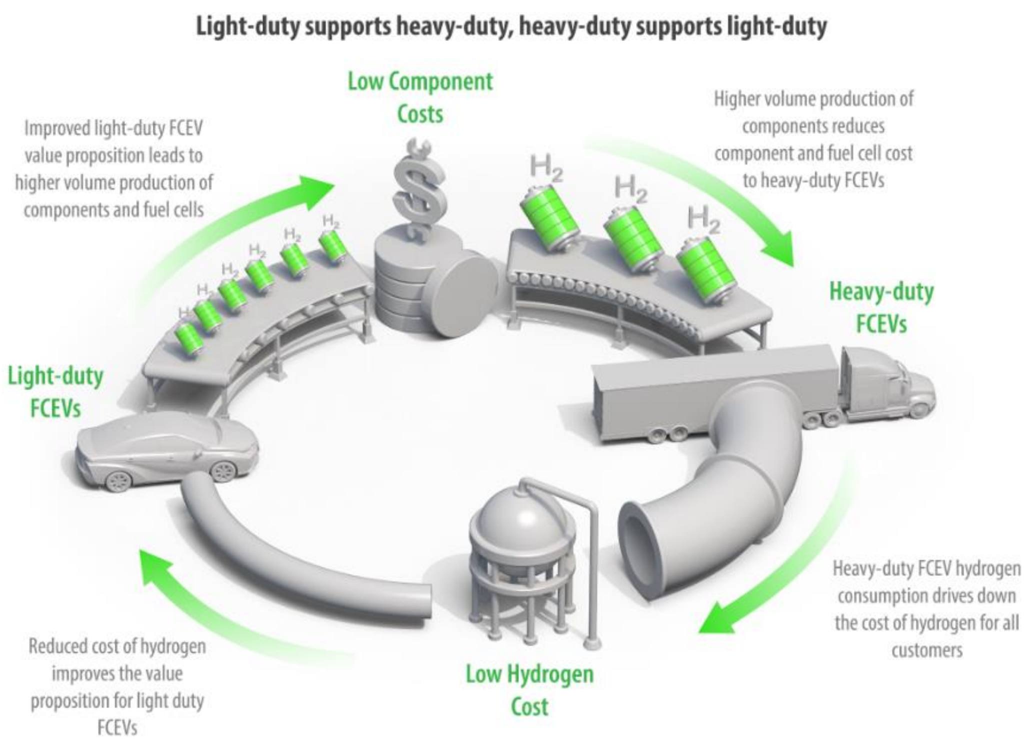


Figure 6. Light Duty Hydrogen Vehicles Support Heavy Duty Vehicles Simultaneously Reducing Component Costs and Hydrogen Cost

Research on HD infrastructure at NREL involves upgrading the existing station equipment to be able to fill a 60kg truck at a rate of 10kg/min. Figure 7, also from the webinar, details the storage needed to be able to do that for gaseous hydrogen (GH2) using a cascade fill method.

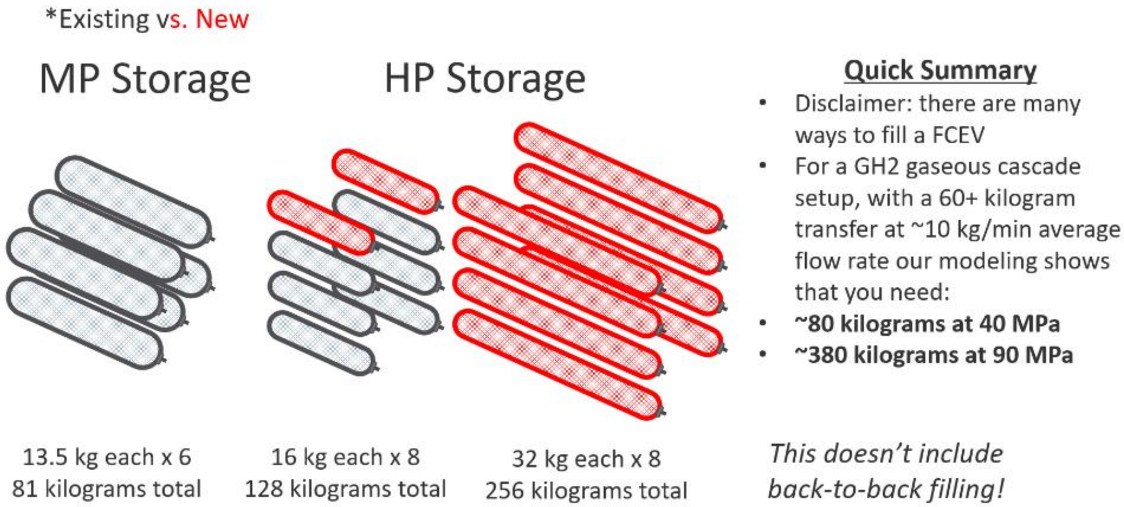


Figure 7. High-pressure Ground Storage Needed for a Single HD Fill (NREL Existing and Future)

Task 3 Title: H2 Contaminant Detector

Task 3 Description

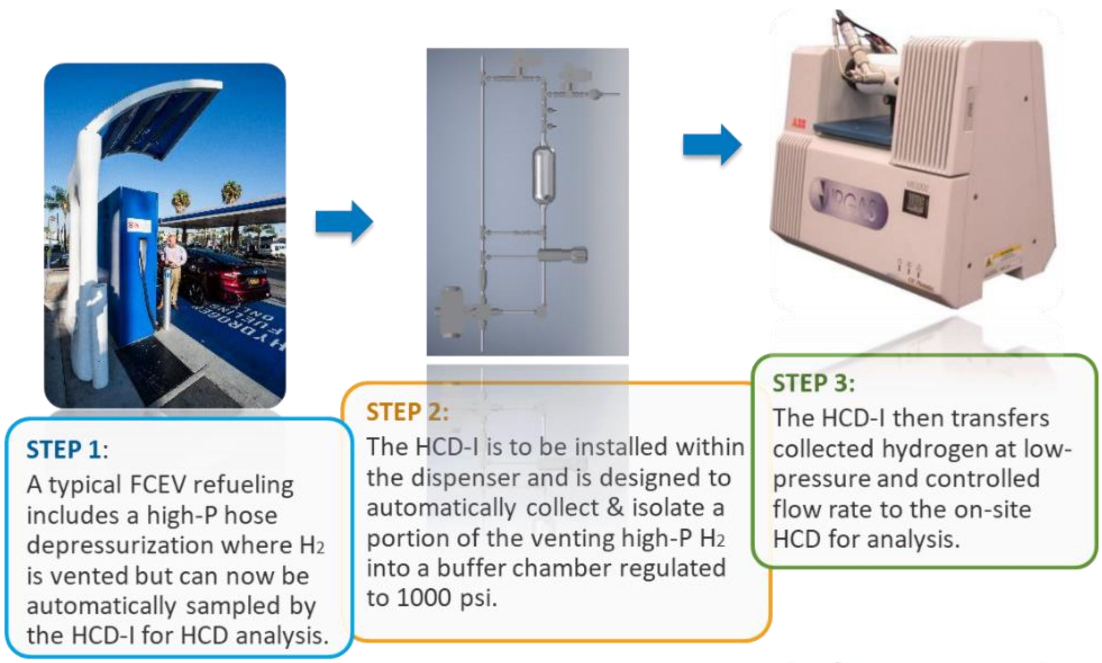
The goal of this task is to complete verification of in-line hydrogen quality detectors prior to validation at retail hydrogen stations.

Task 3 Summary and Outcomes/Results:

Project Summary Report:

NREL Team: William Buttner, Matthew Post, Mariya Koleva, with Kevin Hartmann and Tashi Wischmeyer

FCEVs require high-purity hydrogen, which can be compromised at numerous points in the production, delivery, compression, storage, or dispensing pathways. Fuel quality as prescribed by SAE J2719 (Hydrogen Fuel Quality for Fuel Cell Vehicles) must be verified before commercial dispensing. A low-cost, field-deployable solution for real-time monitoring of fuel quality at hydrogen refueling stations will reduce the likelihood of large-scale fuel contamination events. This task evaluated and adapted mature chemical analyzer technologies for hydrogen contaminant detector (HCD) applications for deployment at the forecourt of retail hydrogen refueling stations. NREL performed a survey of potential chemical analyzers for the HCD application and based upon a weighted ranking system of critical performance parameters selected two instruments (HCD-1 and HCD-2). HCD-1 is a commercial FT-IR instrument capable of verifying that the concentration of multiple impurities is within the level prescribed by J2719. Laboratory performance evaluations generated calibration curves for carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O) and ammonia (NH_3). HCD-2 is a carbon monoxide-specific sensor developed by Los Alamos National Laboratory to quantify the level of CO in hydrogen fuel, and its performance was verified by laboratory analysis at NREL. Both HCD-1 and HCD-2 (and other potential analyzers) operate at near-ambient pressure and with a regulated flow rate. To integrate the HCDs into the dispenser, which can operate at pressures up to 13,000 psi and temperatures between -40 ºC and 90 ºC, a special interface (called the HCD-I) was developed to automatically capture high pressure hydrogen directly from the hose following a vehicle fill during the depressurization of the hose. This hydrogen, which would otherwise be vented (hence wasted) is now used for analysis by the HCD. Such an analysis would be performed with every fill. A working model of the HCD-I was built and its operation verified. This system is configurable for integration of an HCD into the hydrogen dispenser within the NREL Hydrogen Infrastructure Testing and Research Facility (HITRF) to allow in-line verification of hydrogen fuel quality.



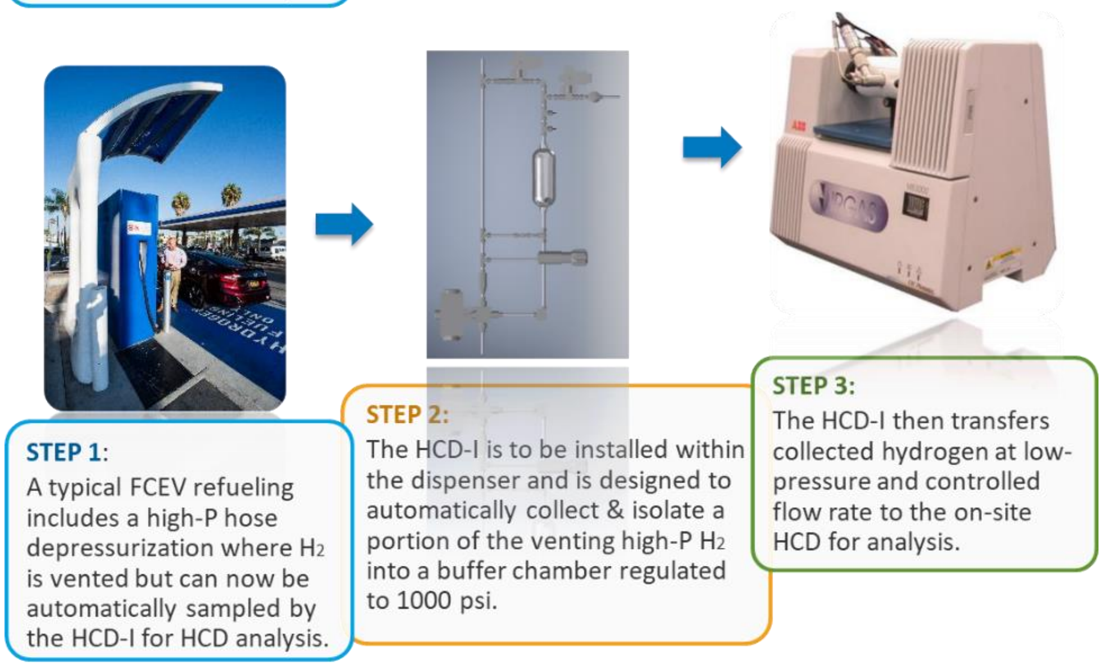


Figure 8. The in-line Hydrogen Contaminant Detector. The HCD will automatically analyze for hydrogen fuel quality following every fill using the NREL HCD-I concept

Phase 2 work:

The HCD project is moving into phase 2. The workplan for Phase 2 includes:

- Integration of HCD-1 and HCD-2 into HITRF using the HCD-I.
- Incorporation of a 3rd HCD for in-line monitoring (e.g., a water analyzer)
- Deployment of HCD-1, HCD-2 and HCD-3 within a commercial fueling station forecourt.

Presentations:

- William Buttner; Matthew Post; Mariya Koleva, Kevin Hartmann. 2021. Hydrogen Contaminant Detector. DOE Hydrogen Program's 2021 Annual Merit Review and Peer Evaluation Meeting. https://www.hydrogen.energy.gov/pdfs/review21/h2042_buttner_2021_p.pdf

Task 4 Title: Nozzle Freeze-Lock Evaluation

Task 4 Description:

The goal of this task is to create an environmentally controlled test setup for identifying conditions leading to nozzle freeze-lock and for verifying solutions.

Task 4 Summary and Outcomes/Results:

NREL Team: Shaun Onorato, Kevin Hartmann, and Daniel Leighton

Hydrogen nozzle freeze-lock occurs when pressurized pre-cooled hydrogen gas is dispensed at-40°C (per SAE J2601 T40 fueling protocols) into a FCEV and causes moisture in the air to build up as frost/ice over on the nozzle's internal and external mechanisms. Under certain ambient conditions, nozzles may temporarily "freeze-lock" to the vehicle's refueling receptacle for an extended period of time until the mechanisms thaw/release. This issue is amplified by back-to-back fueling since the water condensed within the nozzle from previous fills could contribute to re-freezing events in later fills. These occurrences cause extreme customer dissatisfaction and inconvenience, inhibit hydrogen station operation, increase refueling wait times, and create resistance to technology adoption.

NREL developed a nozzle freeze-lock test stand, composed of an atmospheric chamber and atmosphere-generating cart, paired with the existing research-based hydrogen station at the HITRF to conduct real world fueling tests under specific temperature and dew point temperature settings. Figure 9 shows the completed atmospheric chamber and cart. Figure 10 shows the test stand in operation during the summer of 2019.

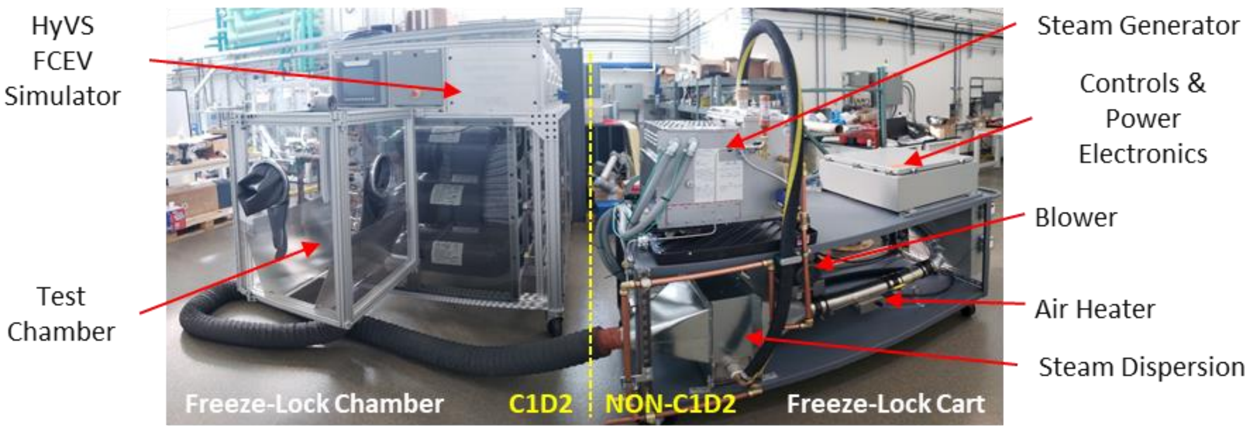


Figure 9. Nozzle Freeze-Lock Chamber and Atmosphere Generating Cart

Figure 10. Nozzle Freeze-Lock Test Stand in Operation (Summer 2019)

The project was executed in three phases:

I. Test stand build-out and baseline analysis starting with ISO/DIS 17268 protocols (2019).

II. Expanded test matrix based on Phase I (2019/2020).

III. Recommended test matrix to evaluate new nozzle designs for manufacturers and station operators (2020).

The test plan was designed with input from industry partners and established SAE and ISO codes/standards. Strategic partners contributing to testing requirements included Toyota Motor Company, Shell Global, South Coast Air Quality Management District (SCAQMD), and the California Air Resource Board (CARB). A defined matrix of temperature and dew points (shown below in Table 1.) was developed to determine where freeze-lock might occur in Phase I. Hot and humid conditions were prioritized based on partner/stakeholder feedback. Based on the Phase I test results, an expanded test matrix was developed to further characterize the conditions under which nozzle freeze-lock occurs (also shown in Table 1). The sequence of tests corresponds to the test phase. Each phase was reviewed with the project team before moving to the next phase.

Table 1. Nozzle Freeze-Lock Test Matrix Phase I

Dew Point Temperature (°C)	Test Temperature (°C) 15	25	28	30	35	36	38	40	45
13.4	Phase I	Phase I	Phase II	Phase II	Phase I		Phase II	Phase II	Phase I
20		Phase I		Phase II	Phase I		Phase II	Phase II	
25				Phase II	Phase I		Phase II	Phase II	
30					Phase I	Phase II	Phase II	Phase II	

The test data was examined in several different ways to help determine if trends exist between temperature, dew point temperature, and fill number (see Figure 11). The results indicate that:

- Freeze-lock occurrence appears more likely at ambient temperatures of 35°C-40°C.
- Freeze-lock occurrence by dew point temperature appears more likely at 20°C-30°C.
- Freeze-lock appears more likely between fill numbers 3-6.

The following figure seeks to explore whether a correlation exists between a combination of test temperature and dew point temperature in relation to observed nozzle freeze-lock events. The chart is organized by nozzle-condition (freeze lock first and shown in red) followed by the other recorded conditions (shown in shades of blue). Each nozzle condition shows the percentage of total observed events for that specific test condition (temperature and dew point) in efforts to show where freeze-lock is likely to occur.

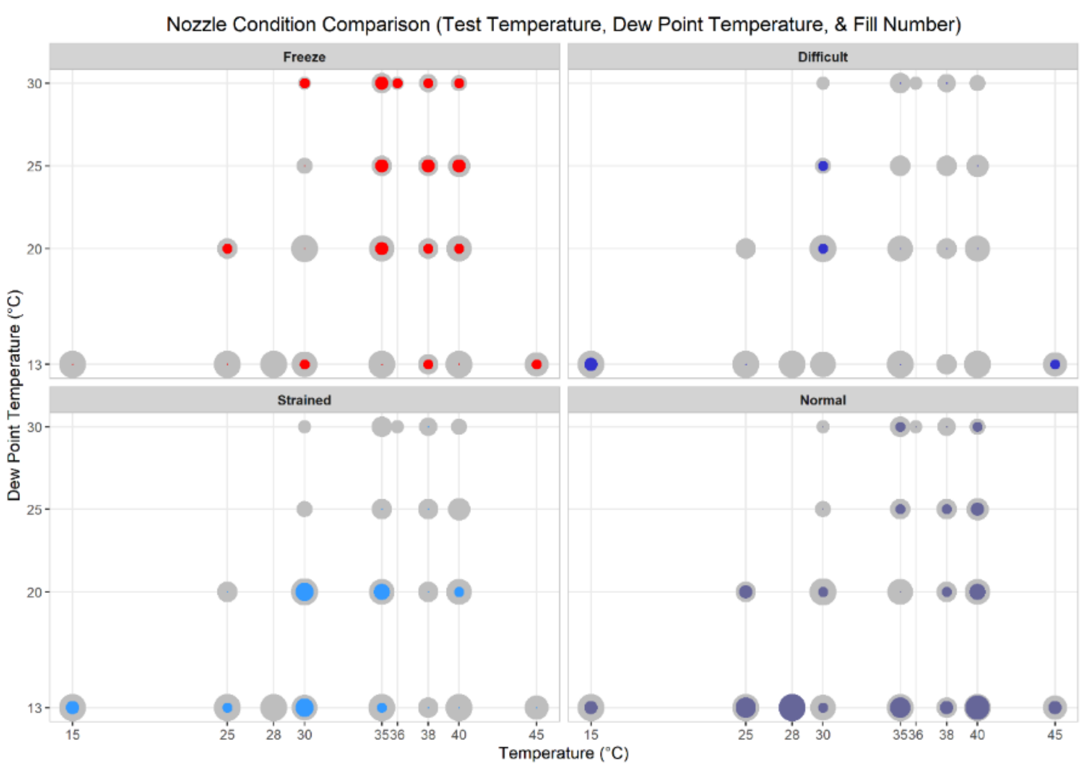


Figure 11. Nozzle Condition Comparison (Test Temperature, Dew Point Temperature, and Fill Number)

Summary of freeze-lock testing:

- Number of freeze events: 41 of 157 fills (26%)
- Temperature with most frequent freeze events: 35°C (10 events)
- Dew point temperature with most frequent freeze events: 30°C (11 events)
- Freeze-lock average time: 25.3 secs
- Longest observed event: 90 sec at 35°C and 30°C Dew Point

As part of phase III of the nozzle freeze-lock evaluation, NREL should recommend a test sequence for evaluating future nozzle designs. Based on the test results, Table 2 shows the recommended order of test points that should be evaluated in three test sets organized by likelihood of freeze-lock (Tests 1, 2, and 3). Test set 1 would be the first round of temperature and dew points evaluated, as these were the areas where freeze-lock occurred the most (highest priority) If further exploratory analyses are desired, test sets 2 and 3 could be utilized (test 3 being lowest priority). The set points showed less likelihood of freeze events occurring during the NREL evaluations.

Table 2. Recommended Test Conditions and Sequence for Nozzle Evaluation

Dew Point Temperature (°C)	Test Temperature (°C)						
	15	25	30	35	38	40	45
13	Test 1	Test 2	Test 3	Test 2	Test 3	Test 3	Test 1
20		Test 1	Test 2	Test 2	Test 2	Test 2	
25			Test 1	Test 1	Test 1	Test 1	
30				Test 1	Test 1	Test 1	

Understanding the conditions where nozzle freeze-lock occurs will help mitigate the issue in retail hydrogen fueling stations. The observed trends help station providers predict days when nozzle freeze-lock might occur and implement proactive countermeasures. To expand on this data set and provide a more comprehensive picture of when freeze-lock occurs, NREL recommends both repeated testing and evaluating nozzles produced by multiple manufacturers. Statistical significance and trends could be further expanded upon. Testing with freeze mitigation technology, such as nitrogen purging, could help determine if mitigation strategies are effective.

The test stand and hardware capabilities developed under this effort will be used for future nozzle evaluations. It is expected that the nozzle freeze-lock cart will be utilized for heavy-duty hydrogen nozzle evaluations in fiscal year 2021 and 2022.

Task 5 Title: CA Hydrogen Integration

Task 5 Description:

The goal of this task is to identify the top priorities for data sharing and experimental scenarios to integrate hydrogen into California's energy management strategies. The task included (1) gathering stakeholder questions and priorities; (2) identifying three topics of utmost priority and providing data and results from exiting hydrogen grid integration and energy storage projects; (3)

identifying gaps in available analyses, and (4) writing a technical report where results revolving around the top three priority questions were discussed.

Task 5 Summary and Outcomes/Results:

Hydrogen has an eclectic mixture of applications in aerospace, transportation, electricity, power-to-gas, and chemical, petrochemical, and food industries, etc. Many of these same sectors contribute to the greenhouse gas emissions in California - a state setting its energy policy targets high as to become carbon-free by 2045. Provided the gas can be produced in an environmentally friendly process, which is efficient and cost attractive, hydrogen can play a key role in decarbonizing the state's economy. Stakeholders were interested in questions such as what the best available technologies are to achieve green affordable hydrogen, what supplementary benefits these technologies can yield, and how they can be integrated into existing technological and market structures.

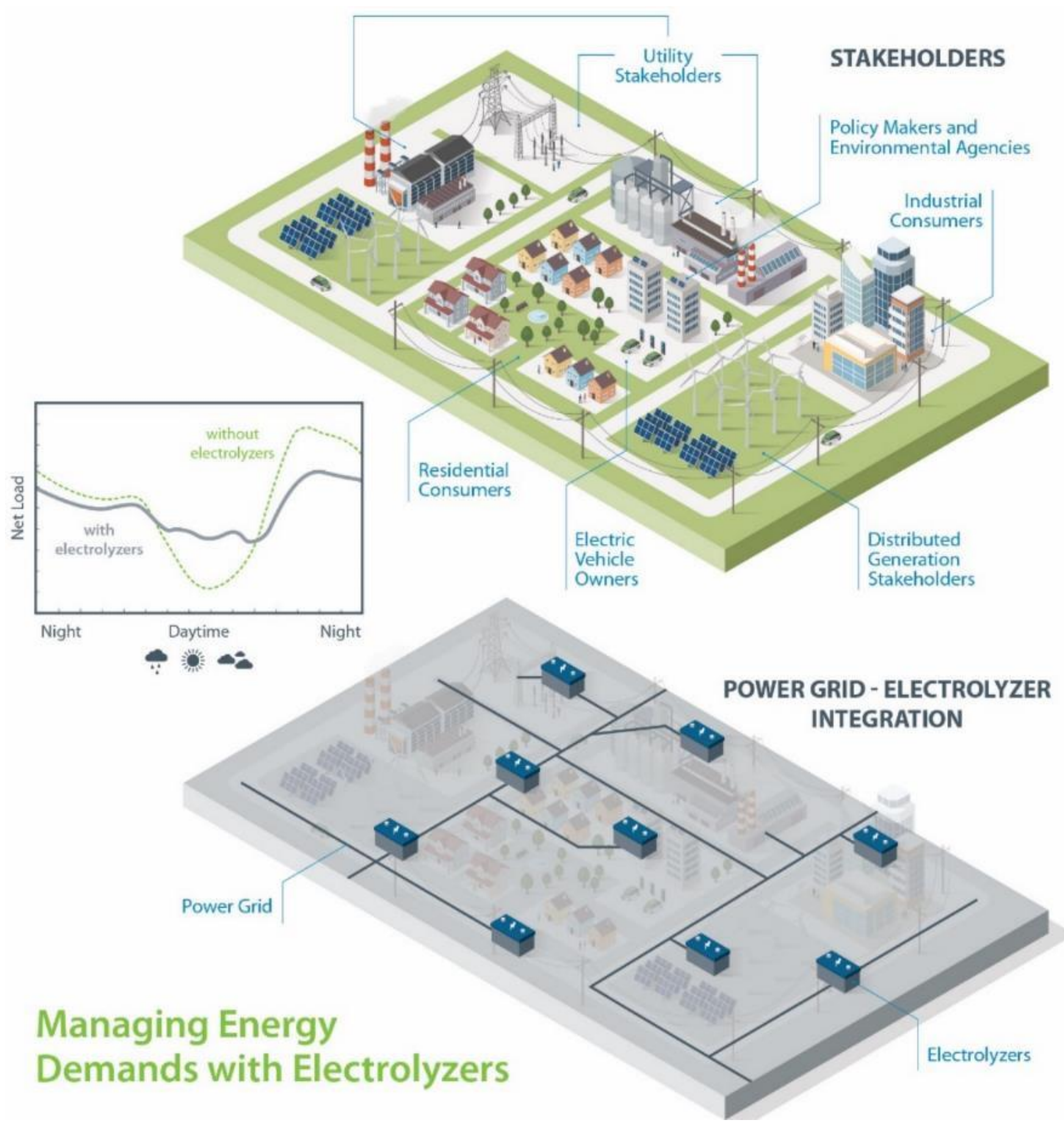


Figure 12. Integrated into the grid, electrolyzers can provide various advantages resulting in flattening out the Duck Curve

Currently, the most common method for hydrogen production is through steam methane reforming, which is carbon intensive without carbon capture. Ongoing research investigates promising green hydrogen production technologies powered by nearly zero-carbon energy, including electrolyzers, biomass converters and reactors, and others. Out of those technologies, electrolyzers have the highest technology readiness level, and the largest R&D portfolio, which has focused on reducing capital investment, the ability to ramp up quickly, and the ability to be integrated with renewable energy sources. Combined with storage, electrolyzers can participate at utility scale for arbitrage.

Recent electrolyzer advances make the technology a suitable mitigator for the arising concerns associated with the duck curve, which mainly have to do with renewable electricity curtailment and ramping of baseload plants (Figure 12). Solving the duck curve requires a combination of approaches including demand response management, electricity rates, battery electric and FCEVs, battery and hydrogen energy storage, minimum generator production, expanding balancing markets, diversification of renewable energy source portfolio, and deployment of fast response technologies. The connective tissue between all those solutions, the electricity markets and valuable commodity production, can easily integrate electrolyzers. Further, research has demonstrated that electrolyzers reduce voltage by 35% and frequency disturbances on the grid by at least 30%.

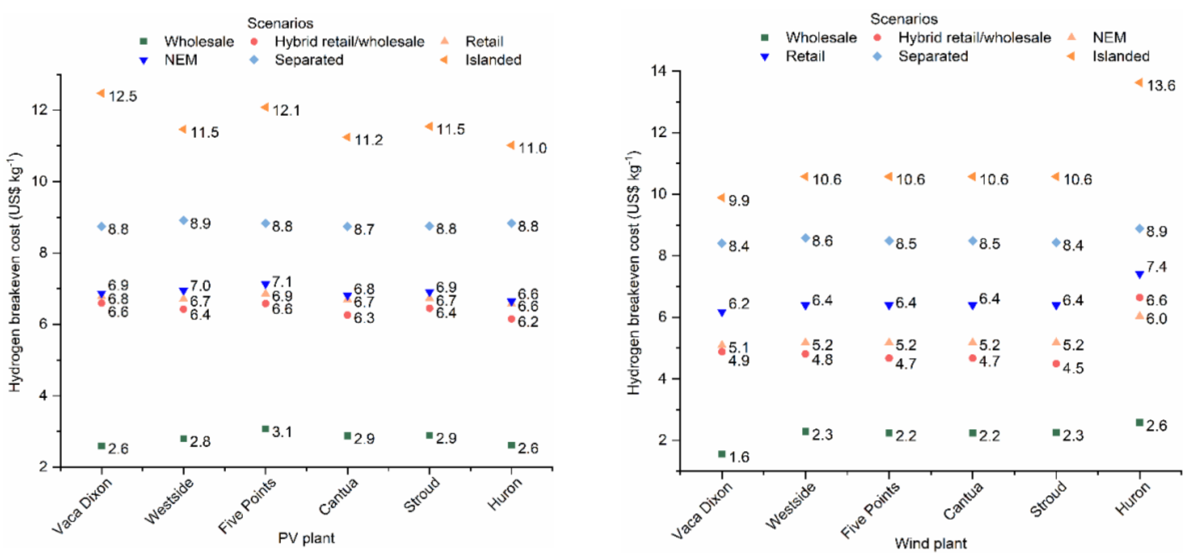


Figure 13. Costs of electrolytic hydrogen production coupled with solar photovoltaic (PV) (left) and wind (right) plants and integrated with current and potential electricity markets including Net Energy Metering (NEM).

Integration of electrolytic hydrogen production with renewables and electricity markets can have a tremendous economic benefit toward the integration of hydrogen in California. A scenario where electricity is bought at retail rates and sold at wholesale rates results in the most cost-effective and realistic configuration, with hydrogen breakeven cost of $4.88 per kg for wind and $6.59 per kg for solar PV. These costs represent, respectively, a 25% and 41% reduction from a scenario where there is no integration between the renewable source and the electrolyzer. Further, both purchasing and selling at wholesale rates result in the lowest hydrogen production cost, but this is an unproven case. Under specific assumptions, integrating wind generation with electrolysis in California has a higher benefit than integrating solar PV with electrolysis (Figure 13).

A detailed description of the studies selected is provided in the internal technical report, which was distributed in 2020. The report covers the following topics/studies:

- Overview of electrolyzers and other existing hydrogen production technologies
- Investigation of the duck curve and H2@Scale for addressing it
- Affordable pathways for hydrogen integration in centralized and decentralized markets

Task 6 Title: Technical Assistance

Task 6 Description:

The goal of this task is to leverage national laboratory technical experts to evaluate questions or issues as they arise as related to California infrastructure development, deployment, and operation.

Task 6 Summary and Outcomes/Results:

The original intent of this task was for NREL experts to be able to assist hydrogen station operators/developers as issues arose. This task eventually was redirected to address a question that came up regarding liquid hydrogen modeling in the Hydrogen Station Capacity Evaluation (HySCapE) tool. The question pertained to the assumed constant density of liquid hydrogen. Some users felt this assumption resulted in an overprediction for the flow rate from the cryopump operation. This task also addressed updating the code to handle the demand for fueling hydrogen trucks at the light duty stations while keeping the refueling rate between the light duty and heavy duty fueling the same. In other words, the updates did not consider higher flow rates for heavy duty trucks. Creating scenarios with higher flow rates was not achievable with the resources reserved for this task, so this work was reserved for a potential future project. The following flow chart in Figure 14 was developed to show how the process would work to account for the density of liquid hydrogen more accurately.

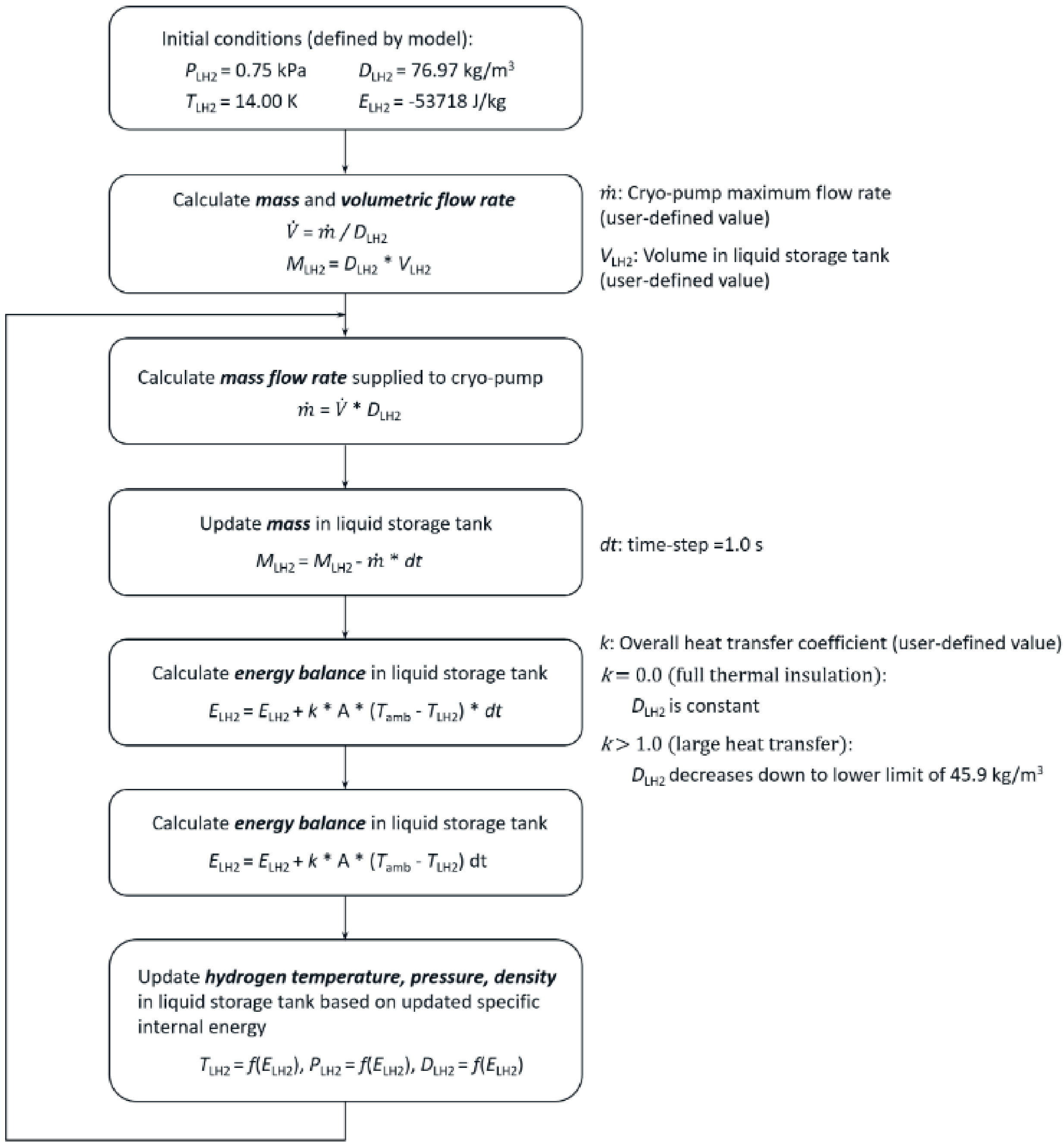


Figure 14. Process for determining the density of the liquid hydrogen that affects the mass flow rate from cryopump.

Although the new way of handling the flow rate coming from liquid hydrogen stations using cryopumps was implemented in simulation code, it was not implemented in the current version of HySCapE for two reasons. First, the current HySCapE model uses simple mass flow calculations without regards for thermal calculations. Second, the quality of the insulation of the liquid tank is not known. The knowledge gained and the code developed will benefit modeling efforts going forward. The developed code calculates the changes in the density and pressure inside the liquid storage tank while that tank is supplying liquid hydrogen to a high-pressure tank through the cryopump.

Updates were also implemented in an offline version of HySCapE to be able to handle demand profiles other than the predefined profile that is based on light duty gasoline stations. New demand profiles can be used for heavy duty trucks. Although this code is implemented in an offline version of HySCapE, it is not implemented in the publicly available version of HySCapE as we did not want to interfere with the current usage of HySCapE for light duty stations. It will be valuable as we develop a heavy-duty version of a station capacity tool in a future proposed project.

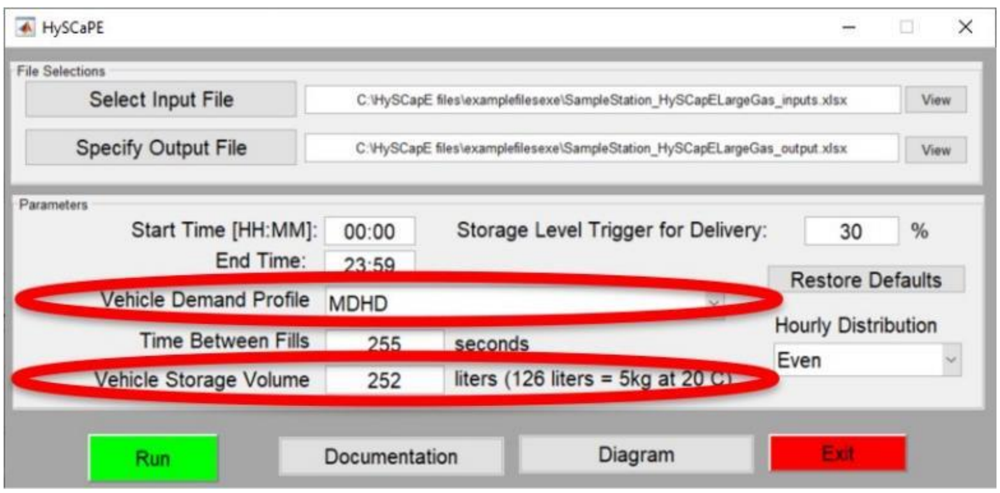


Figure 15. HySCapE updates include adding in MDHD demand profile and updating the tank storage volume.

Medium/Heavy Duty Vehicle demand profile updates summary

- Fills >10kg, demand profile different than Chevron profile.
- Uses a flat/constant demand profile with no variations during the day.
- Doubled the tank size on the vehicles being fueled to 252 liters (10kg).
- Updated graphical user interface (GUI) list to include and load MDHD profile.
- Kept flow rate at 1kg/min for now.

Task 7 Title: Draft and Final Project Report

Task 7 Description:

Prepare a draft project report that includes the results of the tasks listed above. The report shall include the following narrative sections:

- A brief introduction section including a statement of purpose, the scope of the project, and a description of the approach and techniques used during the project.
- A list of the task deliverables previously submitted as outlined in the Schedule of Deliverable Due Dates.
- Any additional information that is deemed appropriate by the Commission Agreement Manager and Contractor's Project Director.

Task 7 Summary and Outcomes/Results:

This CRADA final report will serve to satisfy Task 7. Each task has been described including purpose, scope, description, and any additional information deemed appropriate by the managers of the project tasks.

Overall Summary Conclusion

This close partnership with California agencies is instrumental in further understanding current successes and challenges in the hydrogen fuel landscape in California. We look forward to continuing to pursue hydrogen projects together. Another California consortium project focused on heavy duty vehicle fueling is in development.

References – please refer to publications listed in each task.

Subject Inventions Listing:

None

ROI #:

None